Possible Studies of Parton Distributions at JHF: polarized pd Drell-Yan process

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Abstract

We discuss possible studies of parton distributions at the
proposed 50-GeV PS facility. First, comments are given in
general on the importance of large-x physics for finding new
physics. Second, polarized deuteron reactions are discussed
in connection with new structure functions which are specific
for a spin-1 hadron. Third, if the polarized proton-deuteron
Drell-Yan process is studied at the facility, it could provide
information on the light-antiquark flavor asymmetry in the
polarized distributions.

1 Introduction

Although Q^2 dependence of parton distributions is calculated by perturbative
QCD and it has been confirmed by experiments, the distributions themselves
cannot be calculated without relying on nonperturbative methods. Therefore,
determination of the parton distributions is important for testing nucleon struc-
ture models. However, it is also important for finding any exotic physics signature
in hadron reactions possibly beyond the current theoretical framework.

It is a good idea to study such distributions at the proposed 50-GeV facility in
Japan. At this stage, secondary-beam experiments have been mainly focused in
the proposal, but there are not extensive studies on primary-beam projects. How-
ever, it could be a valuable facility in investigating large-x parton distributions
by using the primary beam. In particular, if the proton polarization is attained,
the facility is a unique one for investigating polarized parton distributions in the
medium- and large-x regions. Although the RHIC-Spin project, for example, in-
vestigates the spin structure of the proton, it measures mainly on the smaller-x
region. In this sense, the 50-GeV facility is compatible with the RHIC-Spin and
other high-energy projects, and it is important for understanding the nucleon
structure in the whole x range.

Because the unpolarized antiquark flavor asymmetry, nuclear structure functions, and the g_1 structure function are discussed by other speakers [1], the author would like to address himself to different topics. In Sec. 2, comments are given on interesting large-x physics. Then, polarized proton-deuteron (pd) Drell-Yan process is discussed for studying unmeasured structure functions for a spin-1 hadron in Sec. 3. Using a polarized pd Drell-Yan formalism, we discuss the possibility of extracting flavor asymmetry in polarized light-antiquark distributions in Sec. 4. The summary is given in Sec. 5.

2   Comments on large-x physics

There are three interesting topics on the large-x physics as far as the author is aware. First, the counting rule is usually used for predicting parton distributions at large x, so that the large-x measurements are valuable for testing the idea. Second, because nuclear corrections are generally large in such a x region, the experiments provide important information on nuclear models at high energies. This topic is related to the first one, e.g. in the studies of F_2^n/F_2^p [2], because the deuteron and ^{3}He targets are used for measuring the neutron structure function. Third, it is crucial to know the details of the parton distributions for finding new exotic signatures. The first two topics are discussed in other publications, so that the interested reader may read for example Ref. [2]. Because the third topic would be much important in relation to other fields of particle physics, we discuss more details.

In the recent years, anomalous events were reported at Fermilab and DESY in the very large Q^2 region. We cannot judge precisely whether or not these are really "anomalous" in the sense that the parton distributions, especially the gluon distribution, are not well known in the large-x region. For example. the CDF anomalous jet data originally indicated that the perturbative QCD could not explain the data. However, noting the gluon subprocesses play an important role in the large-E_T region, we could explain the data by adjusting the gluon distribution at large x [3]. However, nobody knows that this is a right treatment because there is no independent experiment for probing the gluon distribution at such large x. This topic was partly discussed in connection with a possible low-energy facility [4]. This example suggests the importance of the 50-GeV facility by the following reason.

In order to find any new physics possibly beyond QCD, we need to increase the "resolution" Q^2 significantly. Because the momentum fraction x is given by $x = Q^2/2p\cdot q$, for example in the lepton scattering, the large Q^2 roughly corresponds to large x. However, the large-x parton distributions are not necessarily well known as obvious from the interpretation of the above CDF events. What we have been

doing first is to determine the parton distributions at fixed Q^2 ($\equiv Q_0^2 \sim 1$ GeV^2) from various high-energy-reaction data with typical $Q^2 = 1 \sim$a few hundred GeV^2. Then, DGLAP evolution equations are used for calculating the variation of the distributions from Q_0^2 to the large-Q^2 points, where the anomalous data are taken. Therefore, it is crucial to determine accurate distributions at Q_0^2 and especially at large x. Because present high-energy accelerators focus inevitably on the small-x region, they are not advantageous to such physics. The 50-GeV facility should be a unique one in studying the larger-x region. We believe that the primary-beam experiments could have impact on other fields of particle physics if it is properly used.

3 Polarized proton-deuteron Drell-Yan process

Spin structure of the proton has been investigated mainly by polarized lepton-nucleon scattering and will be also studied by polarized proton-proton scattering at RHIC. There are already many data on the structure function g_1 and we have rough idea on the polarized parton distributions [5]. It is desirable to use different observables in order to test our understanding of hadron spin structure. Additional spin structure functions for the deuteron could be suitable quantities. Theoretically, this topic has been investigated in the last ten years, and it is known that there exists a new leading-twist structure function b_1 [6]. Because it has not been measured at all, it should a good idea to test theoretical predictions in comparison with future lepton scattering data. In addition, a theoretical formalism had been completed recently for the polarized pd Drell-Yan process [7]. The results suggested that there exist many new structure functions which are associated with the deuteron tensor structure. There are two major reasons for studying the polarized pd Drell-Yan process. The first purpose is, as mentioned above, to investigate new structure functions which do not exist in the spin-1/2 proton. The second one is to investigate antiquark flavor asymmetry as discussed in Sec. 4.

In this section, we explain the major consequences of the polarized pd formalism without discussing the details. The polarized proton-proton (pp) Drell-Yan process has been investigated theoretically for a long time and the studies are the basis of the RHIC-Spin project. Reference [7] extended these studies to the polarized pd Drell-Yan by taking into account the tensor structure of the deuteron.

A general formalism of the pd Drell-Yan was first studied in Ref. [7] by using spin-density matrices and the Ralston-Soper type analysis. Then, it was found that many new structure functions exist due to the spin-1 nature of the deuteron. The process was also analyzed in a quark model. The hadron tensor is first written for an annihilation process $q + \bar{q} \rightarrow \ell^+ + \ell^-$ by correlation functions.

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They are expanded in terms of the sixteen 4×4 matrices: $\mathbf{1}$, γ_5, γ^μ, $\gamma^\mu \gamma_5$, $\sigma^{\mu\nu} \gamma_5$ together with kinematically possible vectors under the conditions of Hermiticity, parity conservation, and time-reversal invariance. We found in the analysis that there exists only one additional spin asymmetry to the pp Drell-Yan case, and it was called the unpolarized-quadrupole Q_0 asymmetry:

$$A_{UQ_0} = \frac{\sum_a e_a^2 \left[f_1(x_1) \bar{b}_1(x_2) + \bar{f}_1(x_1) b_1(x_2) \right]}{\sum_a e_a^2 \left[f_1(x_1) \bar{f}_1(x_2) + \bar{f}_1(x_1) f_1(x_2) \right]} . \tag{1}$$

Here, $f_1(x)$ and $\bar{f}_1(x)$ are unpolarized quark and antiquark distributions, and $b_1(x)$ and $\bar{b}_1(x)$ are tensor-polarized distributions. The momentum fractions are denoted as x_1 and x_2 for partons in the hadron 1 (proton) and 2 (deuteron), respectively. This asymmetry is measured by using the unpolarized proton and tensor polarized deuteron. It should provide us new information on the tensor-polarized distributions because the unpolarized distributions are well known in the proton and deuteron. If the large-x_F region is considered, Eq. (1) becomes

$$A_{UQ_0}(\text{large } x_F) \approx \frac{\sum_a e_a^2 f_1(x_1) \bar{b}_1(x_2)}{\sum_a e_a^2 f_1(x_1) \bar{f}_1(x_2)} \quad \text{at large } x_F . \tag{2}$$

This equation suggests that antiquark tensor distributions should be obtained rather easily by the quadrupole spin asymmetry in the polarized pd Drell-Yan.

The x dependence of b_1 has been investigated in quark models. The b_1 vanishes in any models with only the S-wave; therefore, it should probe orbital-motion effects which are related to the tensor structure. Because the tensor spin structure is completely different from the present longitudinal spin physics, experimental data should provide challenging information for theorists. Furthermore, it has not been measured at all, so that the proposed 50-GeV facility has an opportunity of significant contributions to a new area of high-energy spin physics.

4 Polarized light-antiquark flavor asymmetry

It became clear in the last ten years that the light-antiquark distributions are not flavor symmetric [8] by the Gottfried-sum-rule violation and Drell-Yan experiments. In particular, the Fermilab Drell-Yan experiments clarified the x dependence of $\bar{u}/\bar{d}$ by using the difference between the pp and pd cross sections. In the same way, the difference between the polarized pp and pd cross sections should be useful for determining the flavor asymmetry in polarized light-antiquark distributions.

There could be two issues in extracting the longitudinal one $\Delta \bar{u}/\Delta \bar{d}$ and the transversity one $\Delta_T \bar{u}/\Delta_T \bar{d}$. First, there was no theoretical formalism of the

polarized pd Drell-Yan before Ref. [7], so that we were not sure how to formulate the spin asymmetry in terms of polarized distributions. Now, this issue has been clarified [7] and we can discuss the cross section ratio pd/pp by using the results. Second, nuclear corrections should exist in the deuteron. However, they are not the essential part, so that they are neglected in the present studies. If experimental data are obtained in future, such corrections should be taken into account carefully.

If higher-twist effects are neglected in the longitudinal and transverse spin asymmetries, the expressions for the cross-section ratios are given by

$$R_{pd} \equiv \frac{\Delta_{(T)}\sigma_{pd}}{2\,\Delta_{(T)}\sigma_{pp}} = \frac{\sum_a e_a^2 \left[\Delta_{(T)}q_a(x_1)\,\Delta_{(T)}\bar{q}_a^d(x_2) + \Delta_{(T)}\bar{q}_a(x_1)\,\Delta_{(T)}q_a^d(x_2) \right]}{2\sum_a e_a^2 \left[\Delta_{(T)}q_a(x_1)\,\Delta_{(T)}\bar{q}_a(x_2) + \Delta_{(T)}\bar{q}_a(x_1)\,\Delta_{(T)}q_a(x_2) \right]} , \quad (3)$$

where $\Delta_{(T)} = \Delta$ or Δ_T depending on the longitudinal or transverse case. If the valence-quark distributions satisfy $\Delta_{(T)}u_v(x \to 1) \gg \Delta_{(T)}d_v(x \to 1)$ at large $x_F = x_1 - x_2$, Eq. (3) becomes

$$R_{pd}(x_F \to 1) = 1 - \left[\frac{\Delta_{(T)}\bar{u}(x_2) - \Delta_{(T)}\bar{d}(x_2)}{2\,\Delta_{(T)}\bar{u}(x_2)} \right]_{x_2 \to 0} = \frac{1}{2}\left[1 + \frac{\Delta_{(T)}\bar{d}(x_2)}{\Delta_{(T)}\bar{u}(x_2)} \right]_{x_2 \to 0} . \quad (4)$$

Namely, the deviation from one indicates the difference between $\Delta_{(T)}\bar{u}$ and $\Delta_{(T)}\bar{d}$ directly. On the other hand, if another limit is taken $x_F \to -1$, the ratio becomes

$$R_{pd}(x_F \to -1) = \frac{1}{2}\left[1 + \frac{\Delta_{(T)}\bar{d}(x_1)}{4\,\Delta_{(T)}\bar{u}(x_1)} \right]_{x_1 \to 0} . \quad (5)$$

The factor of 1/4 suggests that the ratio of this region is not as sensitive as the one of the large-x_F region.

We discuss numerical results for the ratio R_{pd} in Fig. 1 [9]. For the parton distributions, we use a recent parametrization in Ref. [10] at $Q^2 = 1$ GeV^2. The transversity distributions are assumed to be the same as longitudinally-polarized ones. Then, three ratios are assumed for the antiquark distributions: $r_{\bar{q}} \equiv \Delta_{(T)}\bar{u}/\Delta_{(T)}\bar{d} = 0.7$, 1.0, or 1.3. Then, they are evolved to $Q^2 = M_{\mu\mu}^2 = 25$ GeV^2 by the LO-DGLAP evolution equations. The numerical results indicate that the

Figure 1: Drell-Yan cross section ratio $R_{pd} \equiv \Delta_{(T)}\sigma_{pd}/2\Delta_{(T)}\sigma_{pp}$. (from Ref. [9]).

obtained ratios are much different depending on the flavor-asymmetry ratio $r_{\bar{q}}$ particularly in the large-x_F region. Therefore, the measurement of this ratio could determine $r_{\bar{q}}$ and it should be an important test of theoretical models for explaining the unpolarized flavor asymmetry.
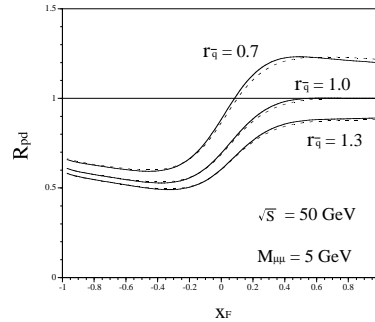
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5 Summary

We discussed first why the 50-GeV PS facility is important for structure-function studies in the large-x region. Then, specific topics are discussed by using polarized deuteron. We explained that the polarized proton-deuteron Drell-Yan process is interesting in two respects. First, it should be valuable for finding new tensor structure functions in the deuteron. Second, it could be used for studying flavor asymmetry in the polarized light-antiquark distributions. Because these topics are not investigated by other facilities, possible 50-GeV data should provide important information on hadron spin structure.

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